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GOLF SIMULATOR OR MEASUREMENT APPARATUS

The present invention relates to a method and apparatus for simulating or measuring the movement characteristics of a ball which has been struck from a stationary position by a moving object. The invention relates more specifically, but not exclusively, to a method and apparatus for simulating or measuring the movement characteristics of a golf ball, which has been struck by a golf club in a shot which may comprise a drive shot.

The game of golf is one of the most popular universal sports. As is well known, it comprises sets of shots, each set typically involving an initial long drive shot from a starting tee, followed by a series of progressively shorter shots towards a hole on a green.

Most golf players, from beginners to professionals, reserve their greatest interest for the initial drive shot. It is this shot, which provides the greatest level of satisfaction when well hit and which has the most deleterious effect when badly hit. It receives far more attention and practice off the course than its relative frequency would otherwise warrant. The drive shot retains an element of intrigue for most players because its dynamic characteristics are beyond the normal range of human perception. The transfer of energy to the ball is so rapid that the ball has departed far from the tee before the player can register the impact either by feel or sight. For example, in a well hit golf drive shot the ball and club face are typically in contact for only about 0.45 ms, during which time the ball moves about 15 mm to 20 mm, and the average force between the ball and club face is around 12,000 N to 13,000 N. The ball departs from the club face at a speed of about 65 m/s. The ball also acquires significant spin motion from the driving shot, typically acquiring a back spin about a horizontal axis of around 3,500 rpm but no significant spin in the direction of travel of the ball. The ball may also acquire a side spin component about a vertical axis, which when combined with its back spin, causes a resultant spin about an axis tilted in a plane which is perpendicular to the direction of travel of the ball. The side spin component is not always present and its magnitude is typically less than a few percent of that of the back spin component on well hit drive shots. During impact, typically about 39% of the club head energy is transferred to the ball, about 8% is lost and about 53% is

retained in the club head. Usually, over 99% of the ball's energy is acquired as linear kinetic energy, with spin energy accounting for less than 1%.

The prior art has produced various means whereby the initial drive shot can be carried out away from the golf course to allow player practice or to permit measurement of the characteristics of the drive shot.

The most common means for player practice is the dedicated driving range. In a typical arrangement, players are positioned in a row, are each supplied with a quantity of balls and drive the balls from a tee piece out across the practice range. The range is usually several hundred meters long and may be supplied with markers which indicate the distance from the driving position. Typically, the range is outdoors and the player position is under cover.

Although the dedicated driving practice range is of great benefit to the player, it suffers from several disadvantages. There is usually far more noise and distraction that would occur during normal golfing play. It may be very difficult for the player to see or judge the shot or to discriminate his or her ball, since other players are simultaneously hitting balls, the balls can be very far distant and there can be many stationary balls lying on the range. Furthermore, the location of the range may be inconveniently distant from the player and there may be uncertainty as to whether space will be available when the player arrives. In addition, the range may not be playable in poor light or inclement weather. The driving practice range also has several inherent disadvantages. One inherent disadvantage is that there is no automatic method for statistically measuring performance. Another is that the player cannot maintain his or her stance between shots because of the necessity to look up and follow the progress of the ball.

In another type of driving range, which occurs where space is limited, rows of players are arranged in tiers, with large numbers hitting at the same time into a large enclosure. In this instance, the player has little opportunity to distinguish his or her ball from those of the others players and there is very little feedback of information to the player other than the sound and feel of the shot.

The prior art has attempted to overcome some of the disadvantages of the dedicated driving range. The most successful of these alternatives to the practice driving range appear to be those which allow the player to hit a ball into a large net or screen and which measure the speed and direction of the ball in flight using remote sensors such as electromagnetic wave emitters and receivers. Although they have overcome some of the disadvantages of the driving range, they have achieved very limited success due to several drawbacks. They are very expensive and require a large amount of space to set up. They are not readily portable and many are not suitable for outdoor use. They usually require a substantial electrical power source. They typically do not measure certain important characteristics of ball flight, such as back spin and side spin and in consequence cannot accurately predict the free flight trajectory of the ball. They usually are not compatible with ground shots such as the putting shot.

The prior art has also proposed various alternatives to the practice driving range where the ball is connected or tethered to an apparatus. However, none of these alternatives appears to provide a satisfactory solution. Some simply do not adequately simulate a real practice shot. Those which have attempted to provide adequate or accurate details of the characteristics of the movement of the ball appear to be impractical and to display a failure to appreciate the mechanics of the ranges of golf shots.

Rutherford et al., WO 89/00065, discloses a golf practice apparatus, which comprises a golf ball connected to a shaft. The ball is operable to rotate in a continuous fixed circular orbit in a horizontal plane about a pivot. The practice apparatus roughly estimates the single parameter of shot distance by counting the revolutions of the ball about the pivot. No explanation is given as to how the apparatus will withstand the forces from lofted or badly hit shots. Although the shaft appears to be of rigid construction, no details are given of its construction or of the ball attachment method.

Barry et al., EP 0278150, discloses a golf practice apparatus, which comprises a golf ball connected to a shaft which is operable to rotate in a continuous fixed circular orbit in a slightly

inclined horizontal plane about a pivot. When a shot is taken, the club is caused to pass across light detectors located in the base of the machine. These detectors directly sense the movement of the shadow of the club and an analysis of the movement is made to estimate shot distance and angle. No explanation is given as to how the apparatus will withstand the forces from lofted or badly hit shots and details of shaft construction and ball attachment appear to be impractical.

Onozuka et al., US 4,958,836, discloses a golf practice apparatus, which comprises a golf ball connected to a shaft comprised of an elastic material, which is operable to rotate in a continuous circular orbit about a pivot. The orbit can be selectively set in different fixed planes, all of which are close to a horizontal plane. When a shot is taken, the club is caused to pass across light emitters and detectors located in the base of the machine. These detectors directly sense the movement of the reflection of light from the club and an analysis of the movement is made to estimate shot distance and angle. As with the previous cited specification, no explanation is given as to how the apparatus will withstand the forces from lofted or badly hit shots and details of shaft construction and ball attachment again appear to be impractical.

Russell et al., US 5,997,405, discloses a golf practice apparatus which comprises a golf ball connected to a flexible tether which is operable to rotate in a continuous approximately circular horizontal orbit about a vertical pivot. The practice apparatus roughly estimates the single parameter of shot distance by determining the rate of rotation about the vertical pivot.

Dennesen, US 5,178,393, and Tortola, US 6,257,989, both disclose a golf practice apparatus which comprises a golf ball connected to a flexible tether which is operable to rotate in a continuous approximately circular vertical orbit about a horizontal pivot. The apparatus roughly estimates the shot distance by determining the number of rotations or rate of rotation about the vertical pivot by using an electronic optical sensor, directly wired to the electronic circuitry of the apparatus. The sensor detects the interruption of a light beam passing through a slotted element on a vane attached to the pivot. The Tortola practice apparatus additionally attempts to roughly estimate the direction of the shot by determining the lateral pull at the top of the

flexible tether. This estimate is made using either a pair of strain gauges or a pair of axial optical electronic sensors electrically wired to the circuitry of the apparatus. The strain gauges or axial optical sensors are arranged out of phase to each other to allow determination of the direction of axial movement.

The present invention is more particularly defined in the appended Claims 1 to 116 which are incorporated into this description by reference.

The present invention provides a simulator or measurement apparatus, for use in a ball game where a ball is hit from a stationary position, which includes a ball, a connecting means, a base and a measurement means, where the ball is connected by the connecting means to the base.

The invention relates particularly, but not exclusively, to a simulator or measurement apparatus suited to the game of golf where a golf ball receives an impact from a golf club and the motion characteristics of the ball relate to the initial movement characteristics of the ball. The invention relates more particularly to a simulator or measurement apparatus suited to the game of golf, embracing all golf shots, including the drive shot and the putting shot.

Throughout the specification, where the method or apparatus refers to the game of golf, an apparatus is described which is suited to players who strike the ball to the left, as would normally be the case for right handed golfers. A mirror image arrangement, similar in other respects, can be used for players who strike the ball to the right.

The invention will now be described more particularly with reference to the accompanying drawings which show, by way of example only, an embodiment of the invention which is suitable as an apparatus to measure the movement characteristics of a golf ball which has been struck by a golf club across a range of shots including the drive shot and the putting shot.

In the drawings:

Figure 1 shows an oblique view of the ball and connecting means of a apparatus which simulates and measures the movement characteristics of a golf ball which has been struck by a golf club, the view includes a ball spin rotation pivot, a vertical pivot, a horizontal pivot and a supplemental pivot;

Figure 2 shows an oblique view of the ball and connecting means shown in Figure 1, but with parts, other than shafts and vanes, shown sectioned along a vertical plane through the centre of the ball and ball shaft - the view omits the supplemental pivot;

Figure 3 also shows an oblique view of the ball and connecting means shown in Figure 1, but with parts, other than shafts and vanes, shown sectioned along a horizontal plane through the centre of the ball and ball shaft with upper parts of the horizontal pivot vane casing, and supplemental pivot and vane casing omitted to show the horizontal pivot vane and supplemental pivot vane;

Figure 4 shows an oblique view of the apparatus with the ball in the home position; the view omits a protective housing, display screen, ball retardation means and playing surface;

Figure 5 shows a plan view of the apparatus as shown in Figure 4;

Figure 6 is similar to Figure 5, except that the ball and connecting means have moved away from the home position;

Figure 7 is a sectional end view of the apparatus, taken on X-X as shown in Figure 5; and shows the apparatus with the connecting means orientated in a horizontal plane; the view omits the pinions shown in Figure 5, but includes a representation of the playing surface;

Figure 8 is similar to Figure 7, but shows the connecting apparatus oriented at an angle tilted down from the ball;

Figure 9 shows a diagrammatic plan view of the connecting means and theoretical movement path of the ball where the ball is hit straight along its intended line of direction;

Figure 10 shows a similar view to Figure 9, but where the ball is hit to the right of its intended line of direction;

Figure 11 again shows a similar view to Figure 9, but where the ball is hit to the left of its intended line of direction;

Figure 12 is a diagram showing the relationship between the perpendicular to the free spin axis of a ball and the perpendiculars to two fixed axes set at angles β to the horizontal, where the free spin axis is at a smaller angle to the horizontal than the angle of either of the fixed axes;

Figure 13 is a diagram similar to Figure 12, but where the free spin axis is at a greater angle to the horizontal than the angle of either of the fixed axes;

The following is an index of the reference numerals used in the drawings:

1. Connecting means
2. Ball
3. Ball cavity plug
4. Ball shaft insert
5. Ball shaft flange
6. Ball shaft
7. Ball shaft receiver
8. Outer ball shaft casing
9. Outer ball shaft casing retaining screws
10. Inner ball shaft casing
11. Ball spin-rotation joint
12. Ball spin-rotation vane

13. Docking engagement member
14. Vertical-pivot.
15. Vertical-pivot shaft.
16. Vertical-pivot clevis cheek.
17. Horizontal-pivot.
18. Horizontal-pivot block
19. Horizontal-pivot shaft.
20. Horizontal-pivot clevis cheek
21. Horizontal-pivot vane
22. Horizontal-pivot vane casing
23. Connecting arm
24. Supplemental-pivot
25. Supplemental-pivot shaft
26. Supplemental-pivot connecting arm bush
27. Supplemental-pivot vane
28. Supplemental-pivot vane casing
29. Support bush
30. Playing surface
31. Axis tilt means
32. Axis tilt means crank member
33. Upper pivot connected to the support bushes
34. Upper pivot connected to the base
35. Lower pivot connected to the support bushes
36. Lower pivot connected to the base
37. Upper pivot connecting member
38. Lower pivot connecting member
39. Electrical actuator
40. Threaded bush and lead screw
41. Height setting means
42. Hand wheel

43. Pinion
44. Rack
45. Vertical lifting block
46. Pillar
47. Ratchet and pawl
48. Base

In overview, the ball 2 is connected to the body of the apparatus by a connecting means 1, comprising a ball shaft 6, which is connected in series to a ball spin rotation joint 11, a vertical pivot joint 14, a horizontal pivot joint 17 and a supplemental pivot joint 24. These joints are referred to as the ball spin-rotation joint 11, the vertical-pivot 14, the horizontal-pivot 17 and the supplemental-pivot 24, respectively. The ball spin-rotation joint allows the ball and ball shaft to spin or rotate freely about the shaft axis. The vertical-pivot allows movement in a vertical plane and the horizontal-pivot and supplemental-pivot allow movement in a horizontal plane. The three pivots allow substantially straight line movement of the ball for a short distance when hit from the starting or home position. The spin rotation position of the ball and the positions of the horizontal-pivot and supplemental-pivot are monitored by sensors operating in conjunction with a controller. The apparatus is operable to automatically change the tilt angle of the ball spin rotation axis over successive shots without changing the tee height of the ball. The apparatus is also operable to allow the tee height of the ball to be changed by the player. The part of the apparatus which rests on the ground and generally supports the apparatus is referred to as the base 48 in the description.

The ball 2 comprises a real or simulated golf ball attached to a ball shaft 6. The ball 2 is of the solid type with an exterior which is resistant to wear or cutting. It may comprise one material throughout or may comprise a cover and concentric layers of different materials. Preferably it is of the type which produces high spin rates. For example, it may comprise a relatively hard centre and relatively soft outer layer. The combination of a hard centre and soft outer layer is known to promote high spin rates. The use of a hard centre also facilitates the use of a relatively inflexible shaft connection near the ball centre because there is a reduced tendency for relative

movement where the shaft is connected to the ball material. Also, the relatively inflexible shaft connection interferes less with the natural flexing of the ball 2. Preferably any materials used in the construction of the golf ball do not comprise fillers of the type which are frequently used to increase the density of the ball but which are not otherwise necessary.

Particular care is required in the connection between the ball 2 and ball shaft 6, due to the very high transmitted forces and the difference in flexibility between the ball shaft and ball. The ball shaft is securely connected to the ball and comprises a rigid hollow component. Axial forces in a direction along the axis of the ball shaft, away from the body of the apparatus, are resisted by a rigid external rim or flange 5 on the ball end of the shaft, which bears directly or indirectly against the material of the ball. Where the tapered ball shaft is machined from thick walled tube material, this rim or flange can be conveniently produced in the machining process. Rotational forces between the ball and ball shaft are resisted by a ball shaft insert 4, one side of which is rigidly fixed to the ball shaft and the other side of which comprises projections, such as projecting blades which engage with the material of the ball 2. The ball shaft insert is provided with a short spigot which is positioned in hole in the end of the hollow ball shaft and which is fixed by means such as adhesive bonding or by one or more cross rivets through the spigot and ball shaft. The spigot and hole may also be formed in matching non-circular shapes, to assist the prevention of relative rotation between the parts. The ball shaft insert comprises a relatively strong and rigid material, such as a reinforced polymer moulding or a metal die casting. In an alternative arrangement, the ball shaft insert additionally comprises the retaining rim or flange.

The ball shaft 6 and ball shaft insert 4 are held captive within a cavity in the ball 2. The ball shaft and ball shaft insert are not bonded to the internal surface of this cavity and relative movement can freely occur between the contacting surfaces when the ball 2 is deformed when struck by the club. This avoids failure of the connection by fracture of bonds between rigid and flexible materials when the flexible material is deformed.

The cavity in the ball 2 is created by forming a hole in the ball 2 and then filling it with a ball cavity plug 3 which corresponds to the shape of the hole. The ball cavity plug is assembled on the ball shaft and ball shaft insert, prior to being inserted in the ball 2.

The ball cavity plug 3 comprises a resilient polymer material with a modulus which is similar to or compatible with that of the material in the ball 2, thereby avoiding significant stress concentration occurring at the mating surfaces when the ball is deformed. The material is also chosen such that it can be strongly bonded to the ball material. For example, it may comprise a polymer which is the same or similar to that used in the ball. Bonding may be achieved, for example, by joining the surfaces with a high strength flexible adhesive or by appropriate polymer welding methods.

The cavity plug 3 may be moulded in two halves and assembled on the ball shaft 6 and ball shaft insert 4. Where bonding is by adhesive methods, the outer surface of the cavity plug is in the form of a frustum of a cone with a very shallow taper. The narrow end of this surface terminates in a coaxial cone with a very steep angle or taper corresponding to the shape suitable for the leading face of a milling cutter. A hole is machined in the ball 2 using a rotary milling tool which produces a tapered hole which matches the external shape of the cavity. The cavity plug and corresponding hole are arranged without sharp boundary edges to minimise stress concentration points when the parts are deformed during play. Adhesive is added to the mating surfaces, the two parts are assembled and bonded together. The tapered frustum shape allows the adhesive to remain on the surfaces as the parts are being assembled and allows pressure to be evenly applied to the joint when the parts are brought together. The steeply angled end facilitates machining of the hole. Depending on the materials to be bonded and the adhesive used, the surfaces may require surface preparation. Chemically treating or machining the surface of the anchor and using it with a newly machined hole will usually satisfy any such requirements. Where bonding is achieved by welding methods, the surfaces may be tapered or parallel, depending on the chosen materials and welding methods.

Connecting the ball 2 from the shaft side, has the advantage that it avoids disturbance of the ball cover and underlying material in the region where the ball is struck by the club and where the ball is subject to maximum trauma and distortion.

A reinforcing member, such as a flat ring comprising the same or similar material as the ball cover, may optionally be bonded to the ball 2 where the shaft exits the hole. The cover of the ball 2 surrounding the hole may be lightly machined to a flat surface to receive it, during the hole drilling operation. A reinforcing member is not shown in the figures.

In an alternative embodiment, the core and outer layer of the ball 2 is directly moulded over the ball shaft and ball shaft insert. Similar to the previous embodiment, the arrangement is not dependent on adhesion between the relatively flexible ball material and the rigid material of the ball shaft and ball shaft insert. The contacting surfaces of these parts can move relative to each other when the ball 2 is deformed without detriment to the mechanical connection between them.

In a further alternative arrangement, not shown in the figures, the ball 2 or ball core is comprised of a hollow metal sphere. A ball of this type may, for example, be constructed from stainless steel and comprise dimples to simulate a conventional golf ball. The ball shaft 6 passes though the ball 2 and connects at both sides for added strength. The weight of the hollow ball 2 and the connecting ball shaft are ideally arranged such that their combined inertia is substantially the same as a conventional free golf ball. The wall thickness and wall thickness distribution of the ball 2 may be varied to provide a resilience which presents playing characteristics similar to a conventional golf ball. The weight of the ball shaft and connection may be varied to provide an overall required weight.

Returning to the preferred embodiment, the ball shaft 6 is securely connected to the ball 2 and is arranged such that it does not unduly influence the performance of the ball when struck. The ball shaft is made from a material with a very high strength to weight ratio. Hardened aluminium alloy, grade 7075 T6, has been found suitable. The ball shaft is also shaped such as

to provide high strength to weight performance. It is substantially formed with a tapered exterior and hollow centre. The tapered exterior allows its strength to be varied along its length, providing increasing strength with increasing distance from the ball 2. The hollow centre provides increased rigidity for a given quantity of material.

The dimensions of the ball shaft 6 are arranged sufficiently large to enable it to withstand the considerable stresses which arise when the ball 2 is struck by the club head. The type of stress most likely to cause failure of the ball shaft is bending moment stress caused by the inertia of the ball shaft largely resisting rotational movement about the horizontal-pivot when the ball is struck in a drive shot. The magnitude of this stress is greatest in regions furthest from the ball. It is important to provide a balance which minimises the inertia, yet still provides a ball shaft of sufficient strength. Minimising the inertia within this design constraint has further advantages. It minimises the difference in momentum transfer between the shot and an equivalent free shot taken without a connecting means, thereby making the apparatus operable to provide a shot with a more realistic 'feel'. It also minimises the forces between the ball and ball shaft when a shot is taken, thereby prolonging the life of the ball and its connection to the ball shaft.

The ball shaft 6 terminates in a male threaded section which connects to a corresponding female threaded section on a ball shaft receiver 7. The thread form is arranged such that the normal tendency of the ball 2 to back-spin causes the threaded joint to tighten. A right hand thread is used on apparatus suitable for right handed players. A left hand thread is used on apparatus suitable for left handed players, where the geometric arrangement shown in the figures is reversed.

The ball shaft 6 is arranged such that it and the connected ball 2 are free to rotate about their common axis in a ball spin-rotation joint 11. The ball shaft is supported by a ball shaft casing which comprises an outer ball shaft casing 8 and an inner ball shaft casing 10. Preferably the ball shaft casing is produced from a light weight high strength material such as a reinforced polymer. This lessens its weight and inertia and allows it to be economically moulded to the required shape. Carbon fibre filled nylon provides a high strength solution with permissible

abrasion and friction characteristics. A small clearance is provided between the ball shaft casing and the ball shaft to allow free rotation. Preferably this clearance is such that the ball shaft casing can act as an effective bearing surface for the rotating ball shaft. Although the primary purpose for providing free rotation of the ball is to allow the ball to simulate the spin rotation which occurs with an unconnected ball, the freedom to rotate also reduces stresses which might otherwise damage the structure of the ball and its connection to the ball shaft. It also provides a varying surface on which the ball is struck, thereby spreading wear and increasing the longevity of the ball. The inner ball shaft casing 10 is also provided with thrust bearings which resist axial forces on the ball shaft while the ball shaft is rotating. These thrust bearings comprises passive annular members, concentric with the ball shaft, which bear against projecting shoulders and surfaces on the ball shaft receiver 7. The thrust bearings comprise a low friction material, such as reinforced PTFE, and are fixed in concentric internal recesses or pockets within the inner ball shaft casing 10.

The ball shaft casing comprises two separate parts to facilitate ready replacement of the outer ball shaft casing 8 by the player should this be inadvertently damaged by contact with the club head. The outer ball shaft casing 8 is connected to the inner ball shaft casing 10 by four screw fasteners 9, arrayed symmetrically around the ball shaft and with their axes parallel to the ball shaft axis.

The ball shaft receiver 7 is provided with holding means which is operable to manually prevent its rotation, thereby allowing the ball shaft 6 to be screwed on or off by manually turning the connected ball 2. The holding means comprises a radial hole through the ball shaft receiver which can be aligned with corresponding radial holes in the inner ball shaft casing. Insertion of a pin, through the aligned holes, prevents rotation of the ball shaft receiver relative to the inner ball shaft casing 10. This allows a player to readily replace the ball and ball shaft where an existing one is damaged or worn or where a ball with different play characteristics is required. The holding means is not shown in the figures.

Measurement of the various motion characteristics presents potential difficulties when related to the severe conditions which arise, for example, when the golf ball is struck by the golf club in a drive shot. One of these relates to the shock conditions created by the impact between the ball and club face, where the forces and rates of acceleration are very high. Any parts directly influenced by the motion of the ball may also be subjected to these shock conditions. If appropriate precautions are not taken, these may result in interference with the accurate measurement of the motion characteristics or damage to the measurement means. Further potential difficulties relate to the very fast response which is required due to the high speed of the ball following the impact and to the small distances or angles to be measured.

In the preferred embodiment, measurement is carried out by one or more sensing means which operate in cooperation with a controller means.

The sensing means comprises a target means comprising a target with irregularities. The sensing means also comprises a bridging means comprising an electromagnetic wave circuit, such as an optic light circuit and henceforth referred to as a light, light beam or optic circuit, and an emitter and receiver means which are operable to bridge an opening in the circuit by emitting and receiving light across the irregularities. The target means is located on the portion of the apparatus which endures the greater degree of shock or acceleration and the bridging means is located on the portion which endures the lesser degree of shock or acceleration. The target means is arranged as a relatively simple passive component which is operable to withstand high levels of shock or inertia forces. The bridging means is operable to detect the presence or absence of the irregularities, which may comprise slots or holes, by interruption of the light beam, and thereby detect motion of the target means relative to the bridging means. The light beam is generated from and reconverted to an electronic signal, by suitable electronic apparatus such as a light emitting diode and a photo diode, respectively, and these in turn communicate with a controller, such as a programmed electronic processor, where the electronic signals are processed as required.

The bridging means comprises a light emitter and a light receiver which are held in a spaced apart relationship and are operable to pass a light beam across a gap between them. The target irregularities are passed through the gap and interrupt the light beam. Shock forces are advantageously reduced at the bridging means because direct physical contact is not made with the target means.

A reduced level of shock will usually still occur at the bridging means, due to it being transmitted through the joint of the connecting means 1 or through other interconnected parts. Where the bridging means lies between the ball 2 and one of the other joints of the connecting means, it will still be subject to some degree of rapid acceleration. This shock and acceleration is isolated from the electronic components of the apparatus by arranging the light signals to be communicated from the light emitter and receiver to the electronic components by means of flexible optical fibres. The electronic components may be mounted in a stationary position away from all significant shock forces.

The use of light beam apparatus, directly connected to the region where the electronic controller and apparatus are located, is also advantageous in producing a very rapid response. The signal reaches the electronic components at the speed of light and is then processed by very high speed electronics. The direct communication avoids the need for local electronic apparatus, such as remote amplifiers, which could cause significant response delays.

In the preferred embodiment, the optic fibres comprise single flexible polymer fibres, of circular cross section, with a diameter ranging from about 0.5 to 1.0 mm. The fibres are provided with a protective polymer sheath, which has an external diameter which is approximately twice that of the fibre. The sheath may be omitted in the region of the bridging means and the region where fibres are routed through the pivoted joints to reduce space and routing cavity dimensions. Where unsheathed fibres are used, care is taken to avoid contact between parts where optical leakage may take place, such as where fibres are severely curved.

The bridging means comprises spaced apart opposing fibre ends without additional focusing lens. These fibre ends are those of the emitter fibre and the detector fibre. The fibre ends are polished or otherwise formed flat to improve light transmission efficiency and signal quality. The fibre ends are spaced apart by a distance which is as small as can be practically achieved and approximately equal to twice the diameter of the fibres. The reason for using a small distance is to minimise the diffusion which occurs as light is emitted from the end of the emitter fibre.

The light beam is also passed or received though a collimating slot on the bridging means. The collimating slot has substantially parallel sides and is positioned between the target means and the end of the fibre. The parallel sides of the collimating slot are substantially orthogonal to the direction of motion of the irregularities or slots on the target means and are spaced apart less than the width of the fibre. In the preferred embodiment the width is approximately half the diameter of the fibre. The purpose of the collimating slot is twofold. One purpose is to improve the quality or sharpness of the light signals, meeting or departing the slots in the target means, by providing them with a flat leading and trailing edge. The other purpose is to provide a narrower light beam which increases the resolution of the sensor means by permitting a greater number of vane slots to be used. In some instances, it may be advantageous to use a collimating slot which is much narrower that half the diameter of the fibre, to increase resolution, where there are reasons to maintain greater fibre diameters than would otherwise be required by the bridging means.

The body of the bridging means, including the collimating slots, comprises a polymer moulding which includes the collimating slots and appropriate grooves and supports for the fibres. The fibres may be formed into tight bends as required by the application of moderate heat in the production process. The fibres are fixed in position, by methods such as bonding or clamping. The bridging means is of robust and economical construction.

In the preferred embodiment, the target means comprises a rotary vane with irregularities in the form of open or closed radial slots and teeth around its periphery. The vane may be capable of

limited rotation or of continuous rotation, depending on the type of motion characteristics which are being measured. As the vane rotates, the light beam from the emitter fibre traverses a circular locus on one side of the vane and crosses the slots and interstitial regions to provide a series of on and off signals to the detector fibre on the other side of the bridging means.

It is important that the vane slot spacing is minimised within the design constraints of the apparatus, because in the measurement of certain motion characteristics, the locus of the vane may travel a very small distance through the bridging means. In the preferred embodiment, the width of the slots and the teeth are approximately equal and each is approximately equal to the width of the collimating slot. This will ensure that the beam of light is not spread over more than one slot on the vane. The radial depth of the slots is approximately equal to 1.5-2.0 fibre diameters.

The vane should be constructed with high dimensional accuracy and consistency in the spacing of the slots along the locus of the optic path, since this accuracy and consistency will be directly reflected in the accuracy and consistency of measurements produced by the apparatus. For example, the vane may be constructed from thin stainless steel material produced with a high dimensional accuracy by photo etching. This process produces dimensional accuracies ranging from ± 10% to ± 15% of material thickness. This corresponds to dimensional accuracies ranging from ± 0.02 mm to ± 0.03 mm where a material thickness of 0.2 mm is used. The vane material may advantageously be supported by material which is set back from the edges of the vane slot.

The vanes are enclosed within sealed vane casings to prevent contamination of the optical surfaces or optical path by dust or moisture. Elastomeric seals are used to seal the vane casings where they are penetrated by the rotating pivot shafts.

The circuit carrying the light beam may be routed across the pivoted joints on the connecting means 1, with a portion of the circuit aligned along the axis of the pivoted joint. This is achieved by providing a central passage along part of its axis of the shaft of the pivoted joint and routing a relatively loose, slightly twisted arrangement of fibres through the passage, with

the opposing portions of the polymer fibres in the central passage connected to the portions of the circuit on each side of the pivoted joint. One end of the fibre arrangement in the passage rotates in fixed relationship with one side of the pivoted joint and the other end of the fibre arrangement in the passage rotates in fixed relationship with the other side of the pivoted joint. The relatively loose and slightly twisted centre region of the fibre region twists or untwists a little further with the movement of the joint, but causing only minimal and acceptable strain on the fibre arrangement. In the preferred embodiment, the fibres comprising the ball spin-rotation sensor are routed though cavities in the vertical-pivot and horizontal-pivot shafts 15 and 19 using this method. Similarly, the fibres comprising the horizontal-pivot sensor are routed though the cavity in the horizontal-pivot shaft using the same method. The method has several advantages. The fibres are better protected because relatively loose external loops of fibre are avoided. The fibres are also subjected to less strain than would occur with relatively loose external loops. The connecting means 1 presents a neater and more compact appearance, particularly where parts are exposed to view outside its protective housing.

In the preferred embodiment, each sensing means comprises two bridging means, one of which is asymmetrically set out of phase with the other with respect to the irregularities, such that the on and off signals occur at different times as the vane rotates. This has several advantages. It makes it possible for the controller to detect false signals from the receiver circuits, because a set pattern of signals is expected from the two bridging means as the vane rotates. If one of the receiver circuits provides more or less signals than would be expected in this pattern, the controller detects the error and is programmed to respond in an appropriate manner. For example, where a single bridging means is used, a vane may stop with the light beam just at an edge corresponding to the transition between an on and off signal. Vibration of the system may cause it to repeatedly move between the two signal states, thus giving a false reading. Where a second out-of-phase bridging means is used, one would record no signal change when the other gave such a false signal, thus enabling the controller to distinguish between valid and invalid signals. An additional advantage arises in that the resolution of the sensor is increased because the number of signals is doubled. A further advantage arises in that the sensor is operable to determine the direction of motion of the vane, because clockwise motion will result in a

different pattern to counterclockwise motion due to the bridging means being asymmetrically set out of phase to each other. The two bridging means are located such that one is an even number plus one half slot away from the other. Ideally, one is just one half slot away from the other. Where the two bridging means are adjacent each other, it may be possible to share one emitter fibre between them. In this instance, the collimating slots may conveniently be positioned between the vane and the detector fibres. The emitter fibre may also be of larger diameter than the detector fibres.

The controller or measurement means is also provided with timing means which is operable to measure the time duration between events which are directly or indirectly related to the signals received from the sensing means. This allows fine resolution by interpolation of the measurement of motion of the target irregularities relative to the bridging means. The controller is operable to subdivide a count into smaller divisions to improve the resolution. The measurement of motion is accordingly not limited to the relatively coarse measurement of the number of irregularities passing the sensor between two identified events, but rather the fine measurement of the length of time elapsed between identified events, where these identified events relate to the detection of individual irregularities.

The signal from the pair of bridging means gives four signal events per slot, two positive edges and two negative edges. This gives a measurement resolution of four times the slot spacing. Interpolation of the signals, as described above, increases this resolution by about ten times, or about forty times the slot spacing.

Returning now to Figures 2 and 3, the ball shaft receiver 7 is provided with a ball spin-rotation sensing means to detect the relative rotation of the ball shaft 6 within the inner ball shaft casing 10. The target means comprises a ball spin-rotation vane 12 mounted on the ball shaft receiver and two bridging means mounted in a moulded pocket within the inner ball shaft casing. The location of the sensor means on the ball shaft receiver, at a position which is distant from the ball end, has the advantage that the sensor is subject to far lower inertia forces resulting from the rotation of the ball shaft about the horizontal-pivot or vertical-pivot than it would have if it

were located nearer to the ball 2. The controller monitors the resulting light signals following the impact between the ball 2 and club head and determines certain of the relevant motion characteristics.

The inner ball shaft casing 10 is connected to the apparatus by the vertical-pivot 14, which allows relative rotational movement in a vertical plane. The vertical-pivot has several functions. It allows the ball to assume a natural movement when struck from the start or home position, by providing a vertical component of movement. This provides one of the degrees of freedom necessary to allow the ball to follow its natural movement when struck. It additionally prevents damage to the apparatus by allowing freedom for the ball to move up or down, particularly in the event of a badly hit ball which is hit too high or too low.

Referring to Figures 1, 2 and 3, the vertical-pivot 14 comprises a clevis type pivot joint with a vertical-pivot shaft 15, the axis of which is orientated in a horizontal direction. The inner ball shaft casing is connected to the vertical-pivot by a plurality of clevis cheeks 16 which comprise horizontal holes which engage the vertical-pivot shaft. The vertical-pivot is connected to an adjoining component of the apparatus which is referred to as the horizontal-pivot block 18. A plurality of clevis cheeks on the horizontal-pivot block comprise a horizontal hole and engage the vertical-pivot shaft 15. Washers may be positioned on the vertical-pivot shaft between the adjacent clevis cheeks.

The vertical-pivot 14 is provided with a spring stop means, which is not shown in the figures. The spring stop means is operable to support the arm at a required rest angle, but which allows the ball shaft to rotate downwards if the ball shaft is subjected to a force which might otherwise damage it or another part of the apparatus. For example, it protects the apparatus from damage which might otherwise result from the ball being struck too high by the club head. The spring stop means does not restrict upward rotation of the arm above the rest angle.

In one embodiment, the spring stop means comprises one or two sets of helical springs in moulded pockets in the horizontal-pivot block 18. The spring drives a moulded pin to a stop on

the pocket. The extended position holds the inner ball shaft casing 10 at the correct angle relative to the horizontal-pivot block. The ball shaft 6 and casing can freely rotate upwards and away from the pin. In the event of a shot being inadvertently downwards, the ball shaft and casing can rotate downwards, depressing the pin into the pocket. Where two sets of springs are used, they are positioned on each side of the lower region of the horizontal-pivot block. In an alternative embodiment, the spring stop means comprises a torsion spring with coils mounted coaxially on the vertical-pivot shaft. The end arms of the torsion spring are pre-energised in a position corresponding to the home rest position, with the arms of the torsion spring bearing against stops on the horizontal-pivot block. An extension of one of the torsion spring arms supports the shaft and ball by bearing against the outer arm casing. This extension is operable to deflect and allow the shaft and ball to rotate downwards when subjected to a force significantly greater than that resulting from the weight of the shaft and ball. In another alternative embodiment, the spring stop means comprises a substantially flat spring, one end of which is fixed to the underside of the horizontal-pivot block and the other end of which supports the ball shaft casing by bearing against a bearing surface provided on its underside. The flat spring may be provided with a slightly profiled shape, such as a slightly convex shape elongated along the length of the spring as seen in plan view, which allows the spring to decrease its resistance to deformation when the deforming force exceeds a planned threshold. The threshold force causes the spring to temporarily buckle and allow the arm to rotate downwards. The spring retains sufficient force to subsequently return the arm to the unbuckled state against the resisting force of gravity.

Referring again to Figures 1 to 3, the set of components from the ball 2 to the vertical-pivot 14 are connected to the apparatus through the horizontal-pivot 17, which allows relative rotational movement in a horizontal plane. The horizontal-pivot allows the ball to move away from the club face by providing a horizontal component of movement. This provides another of the degrees of freedom necessary to allow the ball to follow its natural movement when struck. The horizontal-pivot 17 comprises a horizontal-pivot block 18 with a plurality of clevis cheeks, a horizontal-pivot shaft and a connecting arm with a plurality of clevis cheeks which engage with those of the horizontal-pivot block. The horizontal-pivot block and connecting arm comprise a

reinforced polymer similar to the ball shaft casing. The horizontal-pivot shaft comprises an inner part of reinforced polymer and an outer thin walled metal shell. The shaft is fixed to the horizontal-pivot block clevis cheeks and is free to rotate in the connecting arm clevis cheeks.

The horizontal-pivot is provided with a sensing means which is similar in construction and operation to that described for the ball spin-rotation sensing means. The target means comprises a horizontal-pivot vane 21 fixed to the lower region of the horizontal-pivot shaft 19. A horizontal-pivot vane casing 22 is moulded integrally with the connecting arm and two bridging means for the sensing means are mounted in a pocket within the vane casing. The horizontal-pivot sensing means communicates with the controller and is operable to detect changes in the relative angle between the ball shaft axis and the connecting arm axis.

The connecting arm 27 is connected to the apparatus by the supplemental-pivot 24, which allows a further degree of relative rotational movement in a horizontal plane. It allows the horizontal-pivot to move in a horizontal plane by rotation about a second vertical axis. This provides the third degree of freedom necessary to allow the ball to follow a substantially straight line movement, both when struck by the club and for a short period afterwards, when certain of the critical launch conditions are to be measured. The supplemental-pivot 24 comprises a supplemental-pivot shaft 25, a central bush 26 connected to the connecting arm and a set of support bushes, above and below the central bush, which are connected to the apparatus. The shaft is fixed to the bush of the connecting arm and is free to rotate within the two support bushes. The arrangement ensures that the horizontal-pivot shaft and supplemental-pivot shaft remain parallel to each other. The supplemental-pivot central bush and support bushes comprise a reinforced polymer similar to the ball shaft casing.

The supplemental-pivot is provided with a sensing means which is again similar in construction and operation to that described for the ball spin-rotation sensing means. The target means comprises a supplemental-pivot vane fixed to the lower region of the supplemental-pivot shaft. A supplemental-pivot vane casing is moulded integrally with the support bushes and a bridging means for the sensing means is mounted within a pocket in the vane casing. The supplemental-

pivot sensing means is operable to detect changes in the relative angle between the connecting arm axis and the support bushes connected to the apparatus. However, in the preferred embodiment, the vane and vane casing do not form a complete disk, but rather a vane comprising a segment of a disk rotates within a vane casing comprising a larger segment of a disk. The region close to the axis of the supplemental-pivot, where the vane and vane casing are absent, is used to accommodate a strengthening pillar between the upper and lower support bushes.

The supplemental-pivot is also provided with a buffer means which includes a contact member comprising a rotation limiting arm, which is not shown in the figures. This arm is fixed to the supplemental-pivot shaft and extends in the direction of the support body of the apparatus. It is free to move within limits described by the range of shots which is measured by the apparatus. For example, where the range of shots which measured by the apparatus is within ± 15° of the intended direction of the shot, the rotation limiting arm will have freedom to move in all positions which correspond to the ball being hit within ± 15° of the intended direction of the shot, over the region where the ball travels in substantially straight line movement. Contact members are also provided on the base which prevent the rotation limiting arm from moving any appreciable distance outside of this range. The contact members on the base comprise robust buffer stops, made from a resilient elastomeric material, which are progressively deformed by the movement of the arm outside the free limits, providing a cushioned stop on the movement, with minimal generation of noise. The buffer stops revert to their original shape when the arm returns to the normal region corresponding to the ± 15° limits.

The apparatus is additionally provided with a docking means , which is operable to dispose the ball 2 and connecting means 1 in a starting or home position, relative to other parts of the apparatus. The docking means comprises male and female engagement members. The male engagement member is positioned on the exterior of the inner ball shaft casing and is shown in an exaggerated format in Figure 1 and Figures 3-6. The female engagement member is positioned on the base of the connecting means 1 and is shown in an exaggerated format in Figures 4-6. Figure 4 shows the ball in the home position with the docking means fully

engaged. Figure 5 shows the ball away from the home position with the docking means fully disengaged.

The male and female engagement members comprise vee shapes. The female vee shape is at a somewhat shallower angle than that shown in the figures, and its apex is closer to the edge of the apparatus. The components are arranged such that the ball 2 is in the starting home position when the male engagement member is fully entered into the female engagement member. The engagement members are arranged such that they can freely withdraw from each other when the ball moves in the direction of a shot. The shape of the female engagement member is determined by the range of movements which allow the ball to freely move within limits described by the range of shots which is measured by the apparatus, similar to the rotation limiting arm described earlier. For example, where the apparatus measures shots which fall within ± 15° of the intended direction of the shot, the shape of the female engagement member will be such as to allow the male engagement member to freely disengage without bearing against the female engagement member.

The shapes and material of the engagement members are arranged such that the male engagement member, when pressed against the female engagement member, is automatically guided into the central home position. The docking means may also comprise springs which are operable to ensure that the supplemental-pivot is at an angle sufficiently close to the angle corresponding to the home position such that the male engagement member will always engage the entry to the female engagement member when the ball is pushed backwards towards the starting position. These springs, which are not shown in the figures, comprise low force torsion springs which engage the movement of the supplemental pivot when its angle exceeds a value which is arranged to be less than that which corresponds to the entry of the male into the female engagement member, but which do not engage it when the angle does not exceed the normal angle range of shots.

The engagement members are also provided with means which allow one or both of them to deflect if a shot is taken, which is outside the limits where measurement is taken. The

engagement members return to their normal position when the members have disengaged. This is achieved by providing the female engagement member with spring loaded or resilient supports.

The docking means is also provided with a docking sensor means, which is operable to detect the presence of the male engagement member in the home position in the female engagement member. The docking sensor means, which is not shown in the figures, comprises a proximity sensor, such as a Hall Effect type sensor mounted in the interior of the female engagement member and a sensor target, comprising a permanent magnet, mounted in the interior of the male engagement member. The proximity sensor is operable to detect the close proximity of the permanent magnet and to communicate a corresponding signal to the controller, indicating that the docking means and ball are in the home position. The player receives a visible and audible signal that the ball is correctly docked. The visible signal may be given on the screen display. The controller ignores any shots taken from an incorrectly docked starting position.

The docking means is positioned in a region which lies just within the protection of the housing. The connecting means 1 and docking means are arranged such that the axis of the ball shaft 6, at the starting or home position, is in a substantially horizontal plane, and the angle between it and the intended direction of movement of the ball, is less than 90° on the side on which the ball is struck, as can be seen in Figures 4. An angle between 73° and 83°, such as 78°, has been found suitable. This angular set-back has important advantages in the measurement of the motion characteristics of the ball. It has the advantage that the region where the ball is connected to the arm is kept away from the region where the club makes contact with the ball. In addition to keeping this weakened region of the ball away from the contact area, it also reduces the possibility of the club striking the arm where the shot is very badly directed. The angular set-back also advantageously causes the axis of the ball to be approximately perpendicular to the direction of movement during the period after the ball and club face lose contact with each other, in the period immediately following the impact. This assists in promoting realistic ball movement during the period when its characteristics are being measured.

The connecting means 1 is arranged in a manner which minimises the rotational inertia of the moving components of the apparatus about the horizontal-pivot. This is done for several reasons including the provision of a shot that feels and behaves similar to that of a free or unconnected ball. It is also done to minimise the forces on the connecting means 1 and ball 2 when the shot is taken. Subject to a first overriding consideration of keeping the ball sufficiently distant from the stationary body of the apparatus, such that its proximity does not disturb or influence the player's shot, and a second overriding consideration of maintaining the various operating characteristics of the apparatus, the following guidelines should be followed. The distance between the ball and the horizontal-pivot should be minimised. The centre of gravity of the various components should be away from the ball and as close as possible to the pivot point. The weight of the components should be minimised. For similar reasons, the connecting means 1 is similarly arranged to minimise the rotational inertia of the moving components of the apparatus about the supplemental-pivot.

The connecting means 1 is also arranged in a manner such that the club cannot contact and damage the connecting means in the interval when the ball has ended contact with the club. Although the ball will be travelling faster than the club, parts of the connecting means 1 closer to the horizontal-pivot may be travelling at speeds which are less that that of the club. To prevent the possibility of club contact with the connecting means 1, the horizontal-pivot must be set back a sufficient distance from the outside edge of the housing and the ball shaft must be sufficiently less than 90° from the direction of the intended movement of the ball, as mentioned earlier. In addition, the ball must have a sufficiently high coefficient of restitution to ensure that ball speed is always much higher than club speed following the impact between the ball and club. In practice, a medium golf ball coefficient of restitution has been found adequate. The restitution characteristic is commonly referred to in terms of ball 'compression' and should be about 90. Care should be taken not to use balls with unnecessarily high restitution characteristics, because these will increase the forces on the connecting means 1 and ball when a shot is taken.

The connecting means 1 is also arranged such that its components, where possible, are subjected to tension rather than bending stresses when the ball is struck. Bending stresses on the connecting means 1 are potentially much higher that tensile or compressive stresses and more liable to cause failure or distortion.

The connecting means 1, as described in the preferred embodiment, provides three principal degrees of freedom to the connected ball over a distance sufficient to replicate the motion of an unconnected ball, such that within the limits of this movement, the connecting means 1 is in a unique geometric arrangement for each possible position of the ball. The term 'degree of freedom' refers to each type of two-dimensional means of movement made available to the connecting means 1, including the ability to rotate at a fixed radius about a remote axis, the ability to rotate about an axis passing part of the connecting means 1 and the ability to move in a linear direction without rotation. The invention is not limited in the number of degrees of freedom provided, and as will be discussed later, additional degrees of freedom can sometimes be advantageously provided.

In the preferred arrangement shown in the figures, the connecting means 1 comprises three pivot joints, each capable of partial rotation in one plane, with each joint connected in series between the ball and the body of the apparatus and with an interconnected member between each of the components in series. Two of the pivot joints allow partial rotation in a substantially horizontal plane and the other pivot joint allows partial rotation in a substantially vertical plane. The ball is operable to move freely in three-dimensional space over the limited region where each pivot joint has its interconnected members at an angle which is less than 180° and where the pivot joints remain capable of further rotation. All of the characteristics of motion, other than spin characteristics, are measured while the ball remains in this region. Since, within the limits of such movement, each of the pivot joints and interconnecting members is in a unique position for each possible position of the ball, the movement characteristics of the ball can be determined by timing and measuring the relative positions or angles of the pivot joints or interconnecting members. The spin characteristics may be measured both in this and subsequent regions.

The pivot joint which allows partial rotation in a substantially vertical plane is the first of the three pivot joints on the connecting means 1, closest to the ball. This relative position has the advantage that it allows vertical movement of the ball throughout the shot as the interconnecting member closest to the ball rotates about the pivots which allows rotation in the horizontal plane. If it was not the first joint, it is likely that two degrees of freedom would be required for vertical movement, most probably requiring an additional pivot joint.

The three principal degrees of freedom may also be provided by alternative arrangements. For example, they may be provided by a connecting means 1 comprising two pivot joints, each capable of partial rotation in one plane, and one linear sliding joint. Each joint, along with interconnected members as appropriate, is connected in series between the ball and the body of the apparatus. The sliding joint allows partial extension or retraction of the distance between the ball and the pivot joint nearest the ball. The pivot joint nearest the ball allows partial rotation in a substantially vertical plane and the other pivot joint allows partial rotation in a substantially horizontal plane. The ball is free to move freely in three-dimensional space provided the sliding joint remains capable of further movement and each pivot joint has its interconnected members at an angle which is less than 180° and where the pivot joints remain capable of further rotation. The principal characteristics of motion are measured while the ball remains in this region where it is free to move in three-dimensional space.

As will be discussed later, for a ball of known characteristics, the loft angle of the ball in a lofted shot can be estimated from knowledge of the ball's linear speed and back spin. In the preferred embodiment, it is therefore possible to determine the unique position of the ball with knowledge only of the positions of the two pivots which allow rotation in a horizontal plane, if the back spin can be separately determined. Accordingly, where the back spin is separately determined, the motion characteristics of the shot, including the speed and angle of direction of the shot, can be determined by measuring the angles of these two pivots when the ball is in substantially free movement.

Reference is now made to Figure 9, Figure 10 and Figure 11, which show an application of the preferred embodiment projected onto the horizontal plane. In each of the figures, the solid lines represent interconnecting members between pivot joints at different positions of the ball. The broad dashed line CLM represent the movement path of the ball, with straight line movement along CL and orbital movement along LM. Point C represents the starting position of the centre of the ball. In the starting position, point A represents a pivot joint which allows movement in a substantially horizontal plane between interconnecting member AB and the base of the apparatus, and point B represents a pivot joint which allows movement in a substantially horizontal plane between interconnecting members AB and BC. Line CE represents the direction of travel of a ball which is hit straight. Line CF represents a selected maximum allowable deviation in the direction of travel of a ball hit to the right and line CD represents a selected maximum allowable deviation in the direction of travel of a ball hit to the left. The apparatus is also provided with a pivot joint which allows movement in a vertical plane, but which is not shown in the figures.

Although the movement path of the ball is shown as a straight line in the figures, in practice the movement is partly curved to the right due to forces arising from the interconnected members and pivot. These side forces are relatively small at the beginning of the shot when the connecting shaft is close to being perpendicular to the direction of travel of the ball, but increase as the ball comes closer to the point where it is pulled into circular orbit. In practice, the transition from straight to circular orbit does not occur at a sharp point as shown in the figures. The degree of curvature of the pre-orbit movement also depends on the velocity of the shot. To simplify the figures and to aid description, this curvature is not shown in the figures and the movement which would otherwise be straight line movement is sometimes referred to as *substantially* straight line movement.

Figure 9 shows the arrangement where the ball is hit straight along its intended line of direction. The starting position is arranged such that the angle of pivot joint B, <ABC, is less than 90°, and the straight shot direction is taken as the direction parallel to AB. Accordingly, the ball will travel along path CE if a straight shot is taken, where CE is parallel to AB.

The apparatus is operable to accurately measure the direction of shots over the angle range <DCE, where shots are to the left of centre and over the angle <FCE where shots are to the right of centre.

The apparatus is operable to measure the angle of each of the two pivots joints which allow rotation in a horizontal plane. The apparatus monitors these angles as the shot progresses, where the ball is moving in substantially straight line movement, and determines the angle of direction.

Figure 10 shows the same arrangement but where the ball travels to the right of center along direction CF. The interconnecting member rotates from its starting position at AB, to a maximum clockwise position at AP, where PQ is perpendicular to the line of ball movement CL, and then moves counter-clockwise to the position AK. Simultaneous measurement of the angles at both pivot joints, while the ball is travelling along the straight line path CL, will be sufficient to determine the angle of direction of movement <FCE.

Figure 11 again shows the same arrangement but where the ball travels to the left of center along direction CD. The interconnecting member rotates counter-clockwise from its starting position at AB to the position AK. Simultaneous measurement of the angles at both pivot joints, while the ball is travelling along the straight line path CL, will be sufficient to determine the angle of direction of movement <DCE.

The motion characteristics measured by the method of the invention also include the spin of the ball about an axis through the ball. This aspect of the invention provides a method for calculation of the spin of the ball about its natural spin axis, such as would occur if the ball was unconnected, by measurement of the spin of the ball about different set axes passing through the ball. The method includes connecting the ball such that it is free to spin about these different set axes, and arranging the connecting means 1 to provide these different set axes at successive strikes of the ball. In a preferred embodiment, the apparatus comprises a spin-rotation joint

which is operable to allow the ball rotate about a set axis while connected to the apparatus. The apparatus is operable to measure the speed of rotation and to vary the angle of inclination of the axis about which the ball rotates. The apparatus is also operable to compute the relative components of back spin and side spin by analysis of the speeds of spin or rotation at different set angles of inclination of the axis.

When a free ball is struck unevenly by a flat surface, such as when a golf ball is struck by a golf club, a rotational motion may be transmitted to the ball. In the case of a golf ball being perfectly struck by a club such as a driver, the lofted club face imparts a significant back spin to the ball, causing it to rotate about a horizontal axis. If the ball is unevenly struck, as frequently occurs, an additional component of side spin is imparted and the ball rotates about a resultant axis which is inclined to the horizontal and which is frequently understood by technical golf players in relation to its back spin and side spin components. In practice, over the common ranges of golf ball shots struck with driver or low wood clubs, the axis of rotation is usually within an angle of about ±10° to the horizontal, the direction of slope depending on the rotational direction of the component of side spin. Side spin is important in the game of golf because it can cause significant lateral movement during the flight of the ball. If the resultant axis is tilted down to the right, the ball will drift to the right during flight displaying what is commonly called 'slice' or 'fade' for right handed players, depending on whether the motion is unintentional or intentional, respectively. Tilting down to the left will result in the ball drifting to the left during flight, displaying what is commonly called 'hook' or 'draw' for right handed players, again depending on whether the motion is unintentional or intentional, respectively. The directions are reversed for left handed players.

The method of the invention relates to an insight that when spin is limited to rotation about a specific set axis, a golf ball will spin about this set axis with a spin value which is substantially equal to that which the component of its free or unconnected spin would have, if appropriately projected onto the specific set axis. According to the invention, the appropriate projection is the projection of a spin vector, perpendicular to the axis of free spin, onto a perpendicular to the

specific set axis of spin. Since the spin axis is known to lie in a plane which is perpendicular to the direction of movement of the ball, the projection will lie in this plane.

This is illustrated by the example of a ball which is free to rotate about any axis and which when struck assumes a spin with a magnitude of S about its axis of free spin, which is at an angle of α to a fixed reference axis, such as the horizontal. If this same ball is struck in the same manner, but its axis of rotation is fixed at an angle θ to the fixed reference axis, then the magnitude of its spin will be $S\theta = S.\cos\theta$. If the ball is similarly struck at two different set angles, $\theta 1$ and $\theta 2$, the values of which are known, two values of spin magnitude $S\theta 1$ and $S\theta 2$ will result, which if measured will be sufficient to determine values for S and α.

In one embodiment, two set axes are used, which are tilted at angles of equal magnitude in opposite directions relative to the horizontal.

Reference is now made to Figure 12 and Figure 13, which refer to an embodiment with two set axes tilted at angles β, to the horizontal, one clockwise and the other counterclockwise to it. Lines AF, AE and AG represent perpendiculars to the horizontal, to the set axis tilted to the left and the set axis tilted to the right, respectively. Line AB represents the spin vector and is of length proportional to the magnitude of rotation of free spin, S. It is perpendicular to the axis of free spin and is at an angle of ϕ to the perpendicular to the horizontal, AF, and an angle of θ to the perpendicular to the set axis which is tilted to the right, AG.

Figure 12 relates to the situation where the axis of free spin is at a smaller angle to the horizontal than the angle of the set axis. This results in the spin vector AB being between lines AF and AG. A shot which would result in spin vector AB, when allowed free spin, will result in the projected vector AD where spin is limited to the set axis perpendicular to AD. Line BD is perpendicular to line AG. Similarly, it will result in vector AC where spin is limited to the set axis perpendicular to AC. Line BC is perpendicular to line AE. Since $\theta = (\beta - \phi)$ and AB = S, simple trigonometry yields

AD = S.cos(β - ϕ) and AC = S.cos(β + ϕ), where AD and AC are the measured magnitudes of spin about the two set axes.

Figure 13 is similar to Figure 12, but shows a shot where the angle of the spin axis is at a greater tilt angle than either of the set axes. In this instance, θ = (ϕ - β), <CAB = (β + ϕ) and again AB = S. Simple trigonometry yields, AD = S.cos(ϕ - β) and AC = S.cos(β + ϕ). If absolute values of magnitude are used and due account is taken of whether values are positive or negative, cos(β - ϕ) may be substituted for cos(ϕ - β), whereupon the relationships are the same as those relating to Figure 12.

When the values of the free spin vector S and ϕ are determined, the magnitude of its components can be determined, since back spin = S.cosϕ and side spin = S.sinϕ.

If the two measured values, AD and AC, are found equal, this indicates that side spin is absent. If the value of AC is found to be greater than AD, this indicates that the spin axis is tilted down to the left and the result is a hooked or draw shot. If the value of AC is found to be less than AD, this indicates that the spin axis is tilted down to the right and the result is a sliced or fade shot. The values of measured spin about the two set axes may be processed by a controller in various ways. For example, they may be processed by comparing the relative magnitudes of the two values, since there is a unique relationship between the tilt angle of the axis of spin ϕ and the ratio of the spin values about the two set spin axes for any given value of β.

In an alternative preferred embodiment, two set axes are again used, but in this instance one axis is horizontal and the other is tilted relative to the horizontal. Values measured when the axis is set at the horizontal position give a direct reading of the back spin component and completely filter out the side spin component. If the second axis is tilted down by an angle φ to the right, then where equal spin values are obtained at both axes, this indicates that the free spin axis is tilted down to the right by half the angle φ, corresponding to a sliced or fade shot. If the spin value at the tilted inclination is greater than that obtained at the horizontal inclination, this

indicates a greater degree of slice or fade. If it is less than that obtained at the horizontal inclination, the free spin axis may be tilted to the left, to the right, or not tilted at all, depending on the relative magnitudes of the two values. The relationship can be readily determined by trigonometric analysis similar to that described in relation to Figure 12 and Figure 13.

The preferred embodiment is advantageous where the apparatus is required to additionally simulate and measure the putting shot, because the horizontal axis setting can be used to more realistically simulate the putting stroke. The low energy involved in the putting stroke is also better accommodated because there are no significant gravity effects present when the connecting means 1 operates in a horizontal plane. This embodiment also advantageously reduces the necessary height of the apparatus relative to the height of the ball and thereby minimises player distraction and provides more realistic play simulation.

Various fixed axes angles β or φ may be successfully used in the apparatus. Increases in the tilt angle β will cause the apparatus to become proportionately more sensitive to the measurement of the side spin component and less sensitive to the measurement of back spin component. Increases in the angle are advantageous because the former component is invariably much smaller in magnitude than the latter and is more difficult to measure. It also has the advantage that it will reduce the proportional masking influence of any variations in the back spin component over successive shots. The proportional influence of the set axes angle β can be seen from consideration of its two extreme values. Where β has the extreme value 0°, the apparatus will directly measure the back spin component and will not measure the side spin component at all. Similarly, where β has the extreme value 90°, the apparatus will directly measure the side spin component and will not measure the back spin component at all.

When a golf ball is struck in a drive shot, its rate of back spin is very close to being directly related to its speed and its loft angle. For a given speed and set of conditions, back spin and loft angle substantially follow a unique relationship. Accordingly, it is possible to make a close estimate of loft angle from a knowledge of ball speed and back spin under the known conditions which apply on the apparatus of the invention, and it is usually unnecessary to make a separate

measurement. Alternatively, the loft angle may be determined by providing means to measure the angle of the pivot which allows rotation in a vertical plane. The measurement should be taken when the ball is describing substantially straight line movement because the loft angle will be altered by the restraining force of the arm when the ball is pulled into orbit about the pivots.

The measurements of angle of direction and ball speed may be influenced by loft angle because the effective length of the member connecting the ball to the vertical-pivot, when projected onto the horizontal plane, will change as the ball gains elevation, and this gain in elevation is influenced by the loft angle. The projected length will be the product of the actual length multiplied by the cosine of the angle of the vertical pivot relative to the horizontal. In a drive shot, the vertical-pivot angle, relative to the horizontal, is very small, ranging up to about 4°, where the apparatus has dimensions similar to those described in the preferred embodiment. Since the cosine of 4° is approximately 0.9976, the effect of loft angle is not significant and may be disregarded. If measurements are taken where the elevation of the ball is much more significant, due allowance may be made for the effective change in the projected length of the members in the horizontal plane. When substantially straight line movement changes to orbital movement, the orbital path is substantially an inclined curved arc which reaches its highest point after about 90° of rotation and then gradually descends.

In the preferred embodiment, the apparatus comprises an axis tilt means 31 which is operable to set the axis of rotation of the ball and ball shaft at different angles prior to the shot. As previously mentioned, this provides a means for determining the relative components of horizontal and vertical spin, as would have occurred if the ball had been free or unconnected, by comparing the rotation speeds of successive shots with the axis of rotation at different angles. The axis tilt means is also operable to retain the ball at the same vertical height above the playing surface 30 when the angle of the axis is changed. The purpose of this is to avoid any noticeable change in the starting position of the ball and to retain the same playing height or tee height between shots.

The axis tilt means is operable to either retain the axis at a horizontal angle or to alternate it between two angles, one with the axis tilted downwards from the ball, and the other with the axis horizontal.

Referring now to Figures 4-8, the axis tilt means comprises a quadrilateral pivoting arm arrangement. The arrangement causes back or forth linear movement by an electrical actuator 39 to alter the angle of the ball 2 and ball shaft axis between an orientation which is horizontal and one which is 10° down from the ball.

The quadrilateral arrangement has four pivots 33, 34, two upper pivots and two lower pivots 35, 36. One upper pivot 34 and one lower pivot 36 are pivotally connected to the base of the apparatus. The other upper pivot 33 and lower pivot 35 are pivotally connected to the support bushes 29 which support the supplemental-pivot of the connecting means 1. The two upper pivots are connected by an upper pivot connecting member 37 and the two lower pivots are connected by a lower pivot connecting member 38.

Movement by the actuator 39 is provided by a threaded bush 40 connected to a crank member 52 connected to the lower pivot connecting member 38. The threaded bush is linearly driven by relative rotation of a lead screw which is powered by a small DC motor, mounted on a trunnion support. The motor is controlled by the controller and electrical power is taken from a rechargeable battery. The arrangement is provided with mechanical stops at each end of the required linear movement. The controller is provided with an electronic circuit which is operable to readily detect and react to changes in the back EMF of the motor drive circuit when the motor commences stalling against the mechanical stops. The controller is operable to stop the motor when such changes are detected.

By careful selection of the relative positions and distances between the four pivot centres, it is possible to cause the linear movement to alter the ball shaft axis between the two desired angles and to retain the ball at a constant height. In particular, the distance between the pivots connected to the fixed base is made greater than the distance between the pivots connected to

the support bushes on the supplemental-pivot. The upper pivot connected to the fixed base is set back further than the lower pivot connected to the fixed base.

Figures 7 and 8 show the ball shaft at angles which are horizontal and tilted down 10° from the ball, respectively. The ball remains suspended at the same height above the playing surface at both angle settings of the ball shaft.

Various sets of dimensions can be used with the quadrilateral pivoting arm arrangement to achieve the required axis tilt angles and maintain the ball at the same height. The following dimensions have been found suitable in the preferred embodiment. The lengths of the upper pivot connecting member and lower pivot connecting member are 39.96 mm and 41.82 mm, respectively, measured between pivot axes. The distance between axes of the two pivots connected to the base is 51.77 mm. The distance between axes of the two pivots connected to the support bushes is 42 mm. The upper pivot connected to the support bushes has its axis 10 mm vertically higher than the centre of the ball, and is directly above the axis of the lower pivot connected to the support bushes, when the ball shaft is in the horizontal position. The upper pivot on the base side is 5.09 mm has its axis vertically lower than the centre of the ball and 18 mm behind the horizontal-pivot axis, in a direction which is orthogonal to the intended direction of movement of the ball, when the ball shaft is horizontal.

Referring to Figures 4, 5 and 6, the pivots and pivot connecting members are of elongated shape, the axial lengths of the pivots being much longer than the distance between the pivots. The elongated pivots comprise a large number of clevis joints. The pivot axes are also aligned with the intended direction of movement of the ball and are therefore also approximately aligned with the direction of travel of the club, as projected in the horizontal plane. The arrangement provides a structure which has high strength and rigidity which is appropriately aligned to that which is required when a drive shot is taken. It also provides an arrangement which is clear of the normal path of the club and has a generally low height which is unobtrusive and minimises player distraction.

In an alternative embodiment, the axis tilt means retains the quadrilateral pivoting arm arrangement, but comprises much shorter pivots and pivot connecting members. The axis tilt means additionally comprises an anchor means which securely anchors the axis tilt means to the body of the apparatus but does not impede the required relative movement between the axis tilt means and the body of the apparatus. The anchor means may, for example, comprise one or more retaining members running in one or more curved slots, with the slots orientated in a plane which is substantially orthogonal to the intended direction of motion of the ball.

In a further alternative embodiment, the axis tilt means may comprise a curved sliding or rolling means which corresponds to a portion of an arc of a circle where the centre of the circle corresponds to the position of the centre of the ball and the ball shaft lies along a radius from the ball to the circumference of the circle. The arc is retained in a fixed position, and the radius, along which the ball shaft lies, is rotated between one tilt angle and the other. The ball remains at a fixed height at the centre of the arc. The curved sliding or rolling means may comprise a curved sliding track, a wheeled carriage running on a curved track or a curved track running between fixed wheels.

Referring again to Figures 5-7, the apparatus includes a ball height setting means, which is operable to vary the tee height of the ball above the playing surface in small incremental steps. The ball height setting means 41 comprises a manually operated hand wheel which is directly connected to a small toothed pinion 43a which engages a larger toothed pinion 43b. The larger pinion is connected by a common horizontal shaft to three further similar pinions. The four connected pinions engage with vertical toothed racks which are positioned on the sides of two vertically lifting blocks 45. Each block is mounted around a telescoping pillar 46which is fixed to the base frame of the apparatus. Each pillar 46comprises a set of concentric captive tubes, provided with low friction bushes, with the outermost tube fixed to the block and the innermost tube fixed to the base. The pillars are operable to telescope upwards, providing strong support for the blocks over the required range of tee height adjustment. When the hand wheel 42 is rotated, the set of four pinions rotate and simultaneously lift the racks 44 and blocks. Relatively

large lift pinions are used in order to apply the lift force close to the centre of the pillars, thereby reducing side load forces and consequent friction and wear.

The blocks are directly connected to the base which supports the quadrilateral pivoting arrangement, which in turn is connected to the connecting means 1 and ball. Thus operation of the hand wheel results in direct vertical lifting of the ball. The operator rotates the wheel until the required tee height is achieved.

The lifted components are maintained at the required tee height by a ratchet and pawl 47 arrangement. The ratchet comprises a vertical set of ratcheted teeth positioned on the rear surface of the base which supports the quadrilateral pivoting arrangement, in the region between the two blocks. The ratchet engages a pivoted spring loaded toothed pawl which freely allows upward movement of the ratchet, but prevents downward movement unless the pawl is disengaged by a player operated disengagement means. The disengagement means comprises a simple lever arrangement which pulls the spring loaded toothed pawl away from the ratchet, allowing the lifted components to descend under the force of gravity. The telescoping pillars are provided with enclosed pockets, which compress entrapped air when the pillars descend. The enclosed pockets are provided with small apertures through which the entrapped air gradually escapes and this provides advantageous damping of the downward movement of the lifted components.

The ratchet and pawl 47 provides an advantageous rapid method for resetting a tee-ed up ball to ground level for subsequent fairway and putting shots. The ratchet tooth pitch also provides an advantageous incremental range of tee height settings allowing consistent tee heights to be rapidly achieved. A simple scale and pointer are provided which indicates the tee height setting level.

The ratchet and pawl 47 are shown in Figures 5 and 6. The disengagement means and tee height scale are not shown in the figures.

In an alternative embodiment, the ball height setting means comprises a parallel motion linkage which connects the axis tilt means to the base. The parallel motion linkage may comprise four parallel arms of equal length, with each connected to a pivot on the axis tilt means and pivot on a bracket connected to the base. The axes of the pivots are orientated in a direction which is orthogonal to the plane of the intended movement of the ball. The linkage may be lifted to the required tee height by various means, such as a cam or a rack and pinion arrangement and may be held in the tee-ed position by means such as a cam or a ratchet and pawl arrangement.

Although not shown in the figures, the apparatus also includes a retardation means which is operable to bring the ball to rest after a shot is taken.

In the preferred embodiment, the retardation means comprises a deflector means against which the ball makes contact when it has described an orbit of just less than 180° about the horizontal-pivot. Allowing the ball to move through approximately 180° ensures that a lofted ball will have descended from its orbit to a level similar to the home position level, as the jointed movement is constrained within an approximate spherical orbit.

The retardation means also includes a buffer means which comprises a substantially horizontal energy absorbing surface, the top of which is at a level similar to the lower surface of the ball in the home position. The buffer means comprises a flat flexible receptacle of energy absorbing material, such as gel or sand, with a tough resilient flexible cover. The buffer means is located under the path of the ball in the region to the rear of an extended line running along the front of the apparatus, such that it does not obstruct the swing of the club.

The deflector means comprises a deflector plate which has a soft but durable rubber contact surface facing the direction of the incoming ball and inclined at about 30° to the vertical. Care should be taken to provide a contact surface which emits minimal sound when struck. The ball is deflected downwards by the deflector plate and its energy is substantially absorbed by the buffer means. The deflector plate is operable to recoil from the impact in two recoil modes. One recoil mode comprises the deflector plate pivoting about a pivot at its base, with the pivot axis

in the plane of the contact surface. The second recoil mode comprises the entire deflector plate and its supports pivoting away from the impact about a horizontally orientated pivot. Each recoil movement is ultimately retarded by soft but durable rubber stops. The deflector plate comprises a heavy mass relative to the ball.

The recoil of the deflector plate and the vertical ground resistance of the buffer means, both advantageously contribute to minimising retardation forces which might otherwise cause the apparatus to move relative to the ground when the ball is brought to rest.

The deflector plate is also operable to fold flat onto the buffer for storage and transportation. A safety apparatus, which ensures that it is erect before a shot is taken, operates in the following manner. The deflector plate is arranged such that it can only be folded flat against the action of a spring and the ball connecting means 1 forms part of the arrangement to hold the deflector plate flat for storage or transportation. The deflector plate must be unfolded to the erect position before the connecting means 1 can be released to allow operation of the apparatus.

The retardation means also includes a spring which is operable to return the retarded ball and ball shaft back to the playing area when the shot is complete. The spring movement is limited such that it does not influence the motion of the ball when it is above the play area.

The inner parts of the connecting means 1, the axis tilt means and the ball height setting means are enclosed within a protective housing. The housing has a front and side aperture through which the ball, ball shaft and outer ball shaft casing protrude and which allows movement of the ball and ball shaft. The electronic components, including the controller and display screen, are mounted within the housing or above the housing in a sealed controller enclosure. The housing is also provided with a protective club buffer to prevent damage to the apparatus or the club, or injury to the player, in the event of the club inadvertently striking the housing. The club buffer comprises a resilient rubber moulding fixed to the side of the housing or mounted from the base. The moulding has a sloping surface to deflect rather than abruptly stop movement of the club.

A playing surface, comprising a durable mat and simulated grass surface, is provided under the region of the ball. The playing surface is provided with one or more lines or patterns to indicate the direction of a straight shot to the player. The playing surface is also provided with a tee position marker to assist the player in returning the ball to the home or starting position. The player stands on a platform to elevate his or her ground height to that of the playing surface. The playing surface, housing, ball shaft and outer ball shaft casing are arranged to be as visually unobtrusive as is practically possible. Ideally, they are provided in a dark contrasting colour to the ball, such as dark green, dark grey or black. They may also be provided with camouflage type irregular textures or markings.

It is important that the apparatus provides the required functions with minimal height at the top of the housing, both relative to the ball and to the ground. In the preferred embodiment, the top of the housing nearest the player is similar to or slightly below the height of the top of the ball. This part of the housing is about 90 mm above ground level.

The controller is connected to a display screen, a player selector means and an external signal output port.

The display screen is directed towards the player to allow it to be readily viewed without the need for the player to vary his or her stance between successive practice shots. This is advantageous for the player in isolating and correcting faults or improving specific aspects of play. The apparatus is operable, following each shot, to display values on the screen to indicate the distance the shot would have travelled, if it had been a free or unconnected ball on an open course, and the deviation to the right or left of centre which it would have taken. In addition, it is operable to indicate the proportion of the deviation which is due to incorrect direction and the proportion which is due to hook or slice. Further trajectory details, such as roll-on, may be included, if required. The controller and screen are operable to display these values in various ways. For example, they may be displayed as simple values for the last shot played or they may be displayed in a statistical manner related to previous shots, details of which are memorised by the controller. The player selector means may comprise a keypad which operates in conjunction

with instructions and choices displayed on the screen. The player selector means is used by the player to select various options including the required type of display or settings which simulate different types of playing conditions.

Over the course of a shot, the controller monitors the status of the ball-spin-rotation sensor, horizontal-pivot sensor and supplemental-pivot sensor, recording the characteristics of the detected signals. The angle of direction of movement and the speed of movement are computed over the period when the ball has departed from the clubface and substantially straight line movement takes place. This has several advantages. The measurements are little affected by the elevation of the arm. The measurements are carried out before possible distortion arises from the shock or strain when the ball is pulled into circular orbit. The computations are more acceptable to the player because the measurements are known to be taken with the ball is in realistic straight line movement.

The direction of movement of the ball can be determined by measurement of the angles at the horizontal-pivot and supplemental-pivot because the connecting means 1 is in a unique arrangement for each possible position of the ball, within the limits of such movement.

For a given ball and set of playing conditions, hitting a ball in a specific manner will always result in the same movement characteristics. A mathematical model can be derived which theoretically links the inputs from the various sensor means on the apparatus to the movement characteristics of the connected ball. The mathematical model can be extended to theoretically link the movement characteristics of the connected ball to the movement characteristics of an unconnected ball. When a mathematical model is constructed, the calculations can be executed by conventional sequential electronic processing methods. However, a completely different method and means to determine the movement characteristics of the unconnected ball is used in the preferred embodiment of the invention. This method and means is described below.

The apparatus is provided with a measurement means, which is operable to pre-process or convert the primary signals from the sensor means into data which can be more readily

processed in a subsequent stage. For example, the light pulses from the horizontal-pivot and supplemental-pivot sensor means may be pre-processed or converted to a single vector from the starting position of the centre of the ball to the moving position of the centre of the ball, as the shot progresses, and the light pulses from the ball spin-rotation sensor means may be pre-processed or converted to a changing angle of spin-rotation, as the shot progresses. This pre-processing stage is carried out by conventional electronic processing methods and apparatus. The mathematical models are readily derived by methods including trigonometry and interpolation.

The measurement means is also operable to interpret the pre-processed results in terms of the motion characteristics of an unconnected ball, by using an artificial neural-type intelligence means which has been previously trained with information relating a wide range of pre-processed results to resulting motion characteristics of an unconnected ball. By artificial neural-type intelligence means is meant, determination or problem solving means, which operate in a manner which has similarities to human determination or problem solving. In particular, this type of determination of problem solving relates to previously learned experience from which a solution can be determined or interpolated when a new problem or situation arises. A typical characteristic of this type of determination or problem solving is the use of multiple parallel determination or calculation paths, leading to a solution, rather than a single sequential calculation path as occurs with conventional electronic determination or calculation. Proprietary software and hardware means are available to effect artificial neural-type intelligence, and the preferred embodiment comprises a type commonly referred to as an artificial neural network. An appropriate version uses a trained feed forward system, which produces relevant outputs when relevant information is fed to a set of inputs. A typical example of a simple neural net function is given by $y = f \tanh(dx+b)+g \tanh(ex+c)+a$ where y is the output, x is the input and a to g are training weights. The hyperbolic tan function tanh is a non linear function that can be used with the weights to model the desired process. The network comprises a vast number of functions of this type where weights are automatically adjusted as training progresses. The training and learning process is carried out on a training unit and the results are replicated on

production units of the same characteristics by appropriate electronic programming of their measurement means.

Training of the artificial neural-type intelligence means is carried out using an artificial ball striking means, which is operable to strike the ball in a consistent and repeatable manner and which is operable to be set with variable repeatable settings relevant to the game. In the present instance, the striking means will be referred to as a mechanical golfer. Arrangements are made such that the mechanical golfer can carry out pairs of shots, with equal settings, where one shot strikes the connected ball and the other shot strikes an unconnected ball which is positioned in the same spatial relationship to the mechanical golfer. The mechanical golfer is operable to be set with various ranges of club face settings, including velocity, direction, loft and oblique angle. When each pair of shots is taken, the pre-processed signals from the sensor means provide the inputs and the measured results from the unconnected shot provides the corresponding output. Each set of inputs and outputs is fed into the artificial neural-type intelligence means in an appropriate format to provide a training element. When the artificial neural-type intelligence means has received sufficient of these training elements, spanning examples of the range of possible shots which the apparatus is expected to measure, the artificial neural-type intelligence means will then be operable to predict the outputs corresponding to any shot within the range of the training.

In the preferred embodiment, training is carried out for different categories of shots, and different or partly different networks or programs developed for each category. Taking two extreme examples, different training routines and resulting programs are appropriate for drive shots and putting shots. The motion characteristics of these categories of shot have little in common in relation to learned experience and the artificial neural-type intelligence means is more readily trained and performs better where they are treated as separate categories. The categories of shot which are intermediate between drive and putting shots may also be treated as separate categories, although the proportion of shared motion characteristics increases. Training categories may also be advantageously devised for different playing conditions. For example, training may be carried out on a apparatus with a standard connected ball, matched against shots

with different types of unconnected balls. Inclusion of these programs on the apparatus will allow selection from a range of ball types, with the motion characteristics of the selected ball type accurately represented without the need to change the connected ball on the apparatus.

The measurement means determines the appropriate category of shot in various ways. Distinguishing between drive shots, putting shots and intermediate categories, can be achieved by analysis of the approximate magnitudes of the forward speed and backspin of the connected ball. This determination may be carried out during the primary signal pre-processing stage. Where a setting selection is carried out, as in the example of selected ball type mentioned above, the determination may be made by player manual selection or automatic selection by a remote apparatus, such as computer running a simulated golf game.

Interpretation and presentation of the result outputs from the artificial neural-type intelligence means may be carried out by conventional electronic processing methods.

The use of an artificial neural-type intelligence means, in the manner described above, has several important advantages compared to conventional methods and means. It is capable of more accurately replicating real play. It is capable of replicating play without the need to understand the underlying mechanics of the movement characteristics. It remains open to increased refinement by further training. It is more acceptable to the player because it is based on actual golf play measurement rather than theoretical calculation.

The measurement means is also arranged to be selectably adjusted by the player or by other inputs, such as a game simulation program, to show the motion characteristics which would result with different playing conditions or different playing circumstances. The example of different ball types has already been discussed. The measurement means can also be appropriately adjusted, for example, to allow for different ground or wind conditions. Ground conditions include ground hardness and roughness, which affect how far a ball will bounce or roll. Ground conditions also include the slope of the ground.

The measurement means is additionally arranged to permit calibration of the apparatus. This allows the apparatus to be checked and reset without the need to make mechanical adjustments. In the preferred embodiment, the measurement means is provided with a calibration mode which can be selected using the player keypad. One or more test shots are taken, ideally with a test apparatus such as a mechanical golfer with known characteristics, and the results entered using the player keypad. The measurement means is automatically adjusted to correspond to the test results.

Visual feedback plays no real part in the high speed golf shots, such as the drive shot, because the typical human reaction time for this sense is much longer than the period over which the shot is taken and a ball will have travelled far from its starting position before any visual feedback is registered. The player's actual perception comprises a mixture of the feel of the twist or momentum change in the club head experienced at the top of the club shaft, the sound of the shot and varying psychological preconceptions. The feel of a normal shot experienced through the wrists is far less important than is commonly believed. Although a player will feel the effect of a very bad shot transmitted through the golf club shaft, there is little or no perceptible difference in the feel of a good and a very good shot, with respect to the sense of touch. Similarly, where inertia effects are correctly minimised in the apparatus, there will be little or no perceptible difference between it and the feel of an unconnected shot. The sound of the shot is far more important than is commonly recognised and includes the sound of the impact between the ball and club and the aerodynamic sound of the ball travelling through the air. The aerodynamic component does not naturally occur with the apparatus because the ball is held captive by the connecting means 1. To increase the realistic feel of the shot, the apparatus is provided with a sound synthesiser means which is operable to replicate or exaggerate the sound of an unconnected ball when a shot is taken. Exaggeration of aspects of the sound can be advantageous in screening any sounds which the apparatus may make which differ from the natural shot. The controller is operable to rapidly interpret the type of shot and trigger the sound synthesiser means to deliver the appropriate sound through a sound emitting means such as a speaker. In the preferred embodiment, the sound synthesiser means comprises a conventional electronic apparatus, which is programmed with the appropriate range of sounds.

If not otherwise restrained, the rotation and retardation of the moving parts of the apparatus could cause it to move relative to its ground position. As previously mentioned, this tendency to movement is reduced by the use of recoil elements in the retardation means. The movement is also prevented by the employment of restraining means. In the preferred embodiment, the apparatus is connected to the platform upon which the player stands and the weight of the player and platform prevent movement of the apparatus.

The apparatus is provided with a small free standing safety net to protect against the unlikely event of the ball or other parts breaking away from the apparatus during a shot. The safety net is of much lighter construction than a typical golf practice net because it is permissible for the safety net to travel a small distance when restraining moving parts and also because it does not require to be operable for frequent use. The safety net is also much smaller than a practice net because it can be positioned closer to the apparatus than a practice net, which requires the player to observe the movement of the ball into the net.

An external signal output, such as an output port, is provided to allow the apparatus to be optionally connected to peripheral processing and display equipment, such as computers, computer screens and digital projectors, or to external communications systems, such as telephone or internet connections. The external signal output communicates the relevant signals from the apparatus and is provided at little additional cost. When appropriately programmed, the peripheral equipment may, for example, project a simulated three dimensional representation of the shot on a relatively large screen or display it on a computer monitor. The external output may also used to communicate details of the shot to equipment programmed to assist player instruction, either as an aid to an instructor working with a player or as an interactive aid used by the player without the need for the presence of an instructor. The external output may additionally be used to assist fitting and selection of golfing equipment or to provide an input to golf simulation gaming equipment. By connection to a remote communication apparatus, it also allows two or more players, in remote locations to each other, to play a simulated game of golf.

The following dimensions have been found suitable for use with the preferred embodiment of the invention. The ball has a diameter of 42 mm and a compression of 90. Its centre is 185 mm distant from the centre of the horizontal-pivot axis. The ball is set back in a horizontal plane in the home position, at an angle of 78°, measured relative to the intended direction of travel. The ball shaft comprises hardened aluminium alloy 7075 in T6 temper. It is of hollow circular cross section and has a constant internal diameter of 6.8 mm along its length. It has an external diameter of 11 mm along the region within the ball and has a continuous external diameter of 16 mm in the region within the outer ball shaft casing. The external diameter tapers between 11 mm and 16 mm in the region between the ball and the outer ball shaft casing. The centre of the horizontal-pivot axis is 20 mm distant from the centre of the vertical-pivot axis and 50 mm distant from the centre of the supplemental-pivot axis. The outermost section of the inner ball shaft casing and ball shaft receiver is 44.5 mm from the centre of the horizontal-pivot axis. The outermost section of the outer ball shaft casing extends 30 mm beyond the outermost section of the inner ball shaft casing and ball shaft receiver. The centre of the horizontal-pivot axis lies 40 mm within the perimeter of the protective housing.

The ball spin-rotation vane, horizontal-pivot vane and supplemental pivot vane have external radii of 14 mm, 18 mm and 35 mm, respectively. The vanes are produced in stainless steel with a thickness of around 0.2 mm in the region of the vane slots and with a slot dimensional accuracy of ± 0.02 mm. In an embodiment with optical fibres of 1 mm diameter, the slot and tooth width on the vanes is approximately 0.5 mm and the radial slot depth is around 1.75 mm. The width of the collimating slots on the bridging means is 0.5 mm and the distance between the emitting and detector fibres is 2 mm. The slot spacing on the ball spin-rotation vane, horizontal-pivot vane and supplemental pivot vane is approximately 4.5°, 3.5° and 1.75°, respectively. All of these values are proportionately reduced where optical fibres of smaller diameter are used. Optical fibres of 0.5 mm diameter are used where the production process is capable of controlling tight dimensional tolerances.

It is to be understood that the invention is not limited to the specific details which are described herein by way of example only and that various modifications and alterations are possible without departing from the scope of the invention as defined in the appended claims.

In particular the applicant retains the right to redefine the invention by amending the claims to different combinations of features recited in and between the different groups of claims.